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Air-jet power ultrasonic field applied to electrical discharge

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Abstract

We describe a new setup of the Hartmann air-jet ultrasonic generator combined with electrical discharge in the nozzle-resonator gap. Using the schlieren visualization of air jet and ultrasonic field we investigated the shape and structure of the discharge and we determined relationship among the acoustic field in the nozzle-resonator gap, generator ultrasonic emission and discharge behavior. Apart of the fact that the discharge in the nozzle-resonator gap is stabilized and becomes more uniform, it increases its volume when the generator works in the regime of ultrasonic emission. At the same time the discharge light emission distribution is more over uniform in the gap. In the regime without the ultrasonic emission the discharge light emission is fragmented. We also found that the impedance of the discharge is decreased in case when the generator works in the regime of ultrasonic emission.

Keywords: Air-jet ultrasonic field; electrical discharge

1. Introduction

To improve the quality of environment requires novel techniques based on utilization of wide range of chemical reactions. These reactions apart on the dependence on temperature, on the mixing of reactant medium depend also on the pressure in the volume at which reactions take place [1].

The increase of pressure in this volume can be achieved by application of ultrasonic waves. Thus the effect of a gas-phase mass transfer enhanced by a sound wave on NO reduction from high temperature flue gas was studied in [2]. In this case the gas transfer occurs on a carbon disk target heated to the temperature 973 K.

However many reactions can be intensified by ionization of the reactant medium. The ionization of the medium is most frequently performed by electrical discharges [3]. Combination of ultrasonic waves with electrical discharges at atmospheric pressure is emerging field of research [4], which opens new perspectives in many practical applications such as ozone production, decomposition of nitrogen oxides or decomposition of volatile organic compounds.

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Acoustically assisted discharge ozone production was treated in [5], [6]. It was found that the discharge ozone production was substantially increased when ultrasonic waves were applied on a one-wavelength ultrasonic resonator with nozzle-to-plate DC electrical discharge enhanced by the flow of air through the nozzle.

Important drawback of the approach presented in [5], [6] was that for the production of ultrasound was used piezoelectric transducer/generator, which complicates practical applications (need of additional piece of equipment, transducer to air matching, etc.). In order to eliminate this problem we decided to investigate the possibility to use the air supplied to the discharge for creation of oscillating pressure gradients accompanied by ultrasonic wave generation.

Our original idea therefore includes application of so-called Hartman air jet generator [7]-[12] for generation of ultrasonic waves and their application on electrical discharge. The Hartmann generator represents a combination of a conical nozzle with a resonator and its functioning depends on the proper adjustment of pressure of air supplied to the nozzle and the distance between the nozzle and the resonator.

Schlieren photograph of the supersonic air-jet from the conical nozzle for the pressure of supplied air $p=3\times10^5$ Pa is shown in Fig.1. It shows almost periodic structure of the jet consisting from several sections. The existence of these sections is a consequence of interacting shock waves.

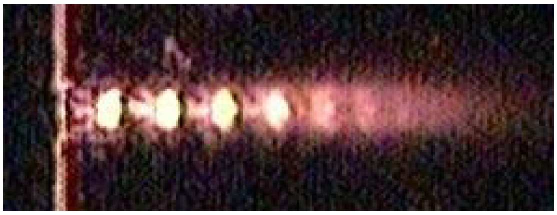

Fig.1 Schlieren photographs of supersonic air-jet from the conical nozzle

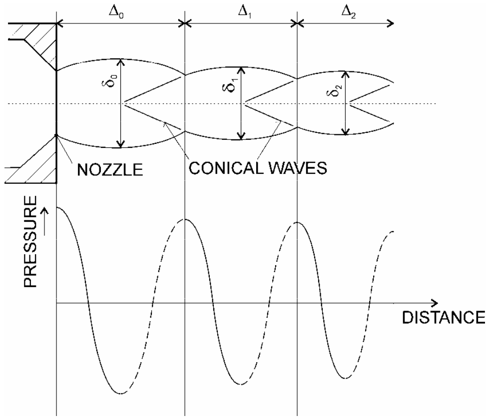

Fig.2 Structure of air jets of supersonic velocity.

As it was shown by Hartman [7]-[12] the above mentioned periodic structure of the jet exists only within a nozzle pressure range from approximately (1.88 to 3.90)$\times10^5$ Pa. The structure of the air jet together with the distribution of pressure as a function of the distance from the nozzle for this pressure range is shown in Fig.2. The first section, the length Δ_0 and the diameter δ_0 is the section at the immediate proximity of the nozzle surface. The length Δ and the diameter δ of particular section are decreased with the distance from the nozzle and depend on the nozzle aperture and the pressure of air supplied to the nozzle.

The rising portion of the pressure curve (shown dashed in Fig.2.) corresponds to what Hartmann has termed "interval of instability". If the orifice O of a cylindrical resonator G, see Fig. 3 is placed in one of those intervals (particularly the first one) a system of powerful oscillations is created. This is the basic principle of the air-jet ultrasonic generator.

In this paper we describe a new setup of the air-jet ultrasonic generator combined with electrical discharge in the nozzle-resonator gap. Using the schlieren visualization of air jet and ultrasonic field we investigated the shape and structure of the discharge and we determined relationship among the acoustic field in the nozzle-resonator gap, generator ultrasonic emission and discharge behavior. We were also able to distinguish the effects of steady supersonic air jet and ultrasonic wave regime on the discharge.

2. Experimental setup

To demonstrate change in the discharge structure and shape due to the application of ultrasound, we used the experimental setup shown in Fig.3.

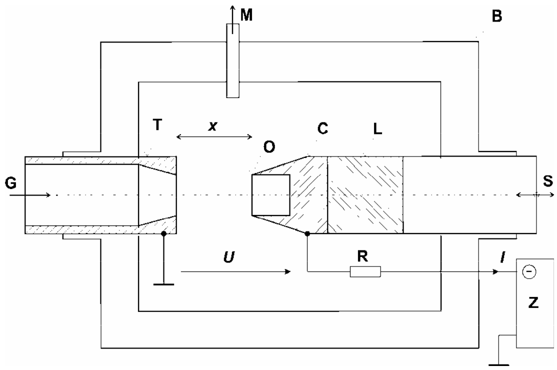

Fig.3 Experimental setup of the generator.

This set up consisted of the discharge electrodes (negatively biased resonator C with a sharp cylindrical orifice O and grounded conical nozzle T); dc power supply Z (0-30 kV); ballast resistor R=6.89 MΩ and air supply system G [3], [4]. The experiments were performed with a constant discharge current I= 0.5 mA. The air pressure in the nozzle was 3×10^5 Pa, the distance x between the conical nozzle T (output diameter 1.6 mm) and the orifice O of the resonator C (diameter 2 mm, depth 2 mm) was changed from 0–10 mm and was adjusted by a shift mechanism S. The resonator was electrically separated from the shift mechanism by an electrical insulator (teflon) L. The exhaust from the discharge cell B is labeled as M.

3. Experimental results

The change in the shape and structure of the streamers in the discharge as well as the gradient density in the discharge region for four different distances x between the nozzle and the resonator is shown in Fig.4-7. The photographs of the discharges for constant currents I=0.5 mA with corresponding discharge voltages U are shown in the left side. On the right side are shown schlieren photographs of air density gradients in the discharge region. The exposition time was 1/40 s.

The regime of the discharge without ultrasonic emission is demonstrated in Fig.4 and Fig.7.

Supersonic stream of air leaving the nozzle enters the cavity of the resonator, returns back along the resonator walls and interacts with another incoming air from the nozzle. This interaction results in formation of the pressure gradients in the vicinity of the resonator orifice, see right sides of Fig.4 and Fig.7. The existence of these pressure gradients results in increased discharge light emission in this region.

The regime of the discharge exposed to ultrasonic emission is demonstrated in Fig.5 and Fig.6. The result of interaction of the oscillating air pressure from the resonator with supersonic flow of air from the nozzle can be seen from schlieren photographs in Fig.5 and Fig.6, right side. Region of the important pressure gradients occupies almost whole region between the nozzle and the resonator orifice. If we increase the distance between the nozzle and the orifice within the rising portion of the pressure curve shown dashed in Fig.2, the occurrence of higher ultrasonic harmonics in the emission spectra of the generator enhances. For the discharge parameters from Fig.5 is emitted the ultrasound with frequencies 25, 50 and 75 kHz, with relative pressure amplitudes 75, 23 and 10. For the discharge parameters from Fig.6 is emitted the ultrasound with frequencies 24, 48 and 72 kHz, with relative pressure amplitudes 42, 5 and 18. Emission of these harmonics was not observed in the schlieren photographs. However from the photographs of the discharge shown in Fig.5 and Fig.6, left side can be concluded that with the occurrence of higher harmonics the number of the streamers increases. At the same time we can conclude that the discharge spreads radially in the vicinity of the resonator orifice, the discharge light emission becomes more uniform and its volume is increased.

Another effect associated with the existence of ultrasonic regime is a sharp decrease of the discharge impedance. Thus for the regime of the discharge without ultrasonic emission (Fig.4) the discharge voltage was 6.8 kV. For the regime with ultrasonic emission (Fig.5) even in the case when the distance x between the nozzle and resonator is increased by 0.45 mm the discharge voltage decreases to 5.4 kV.

One of the best advantages of the described arrangement is stabilization and homogenization of the discharge on the sharp orifice of the resonator. Without the air jet the discharge occurs only in one single point at the orifice.

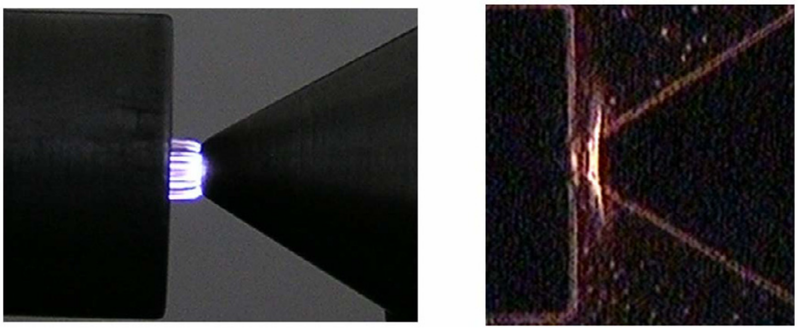

Fig.4 Discharge (left) and schlieren photograph (right) for x =1.5 mm; U=6.8 kV; frequency [kHz] / relative pressure amplitude: 0/0.

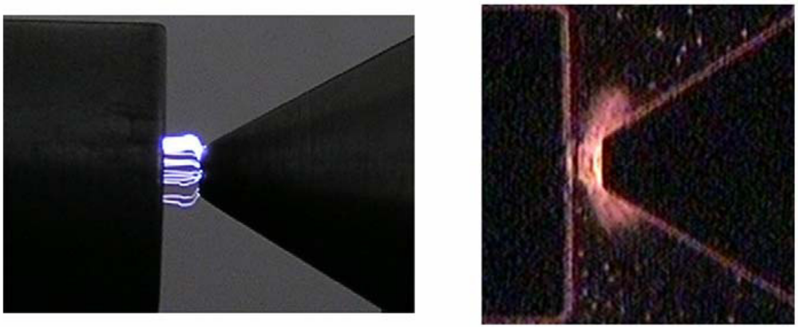

Fig.5 Discharge (left) and schlieren photograph (right) for x =1.95 mm; U=5.4 kV; frequency [kHz] / relative pressure amplitude: 25/75; 50/23, 75/10.

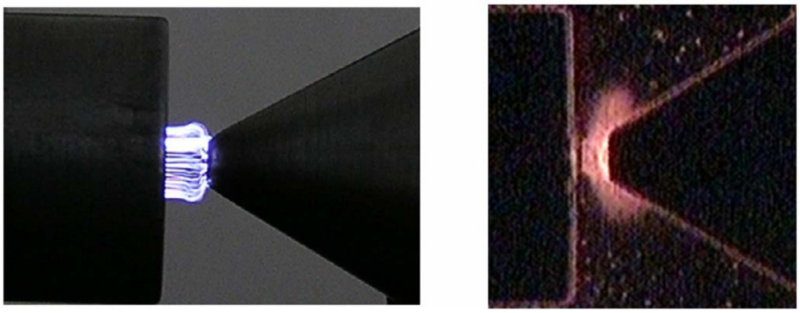

Fig.6 Discharge (left) and schlieren photograph (right) for x =2.2 mm; U=5.7 kV; frequency [kHz] / relative pressure amplitude: 24/42; 48/5, 72/18.

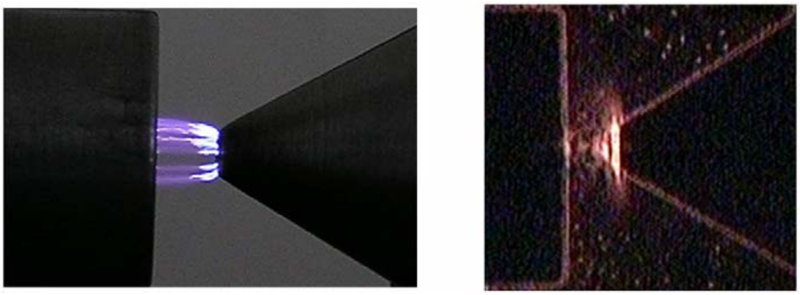

Fig.7 Discharge (left) and schlieren photograph (right) for x =3.4 mm; U=11.1 kV; frequency [kHz] / relative pressure amplitude: 0/0.

4. Conclusion

Our work was focused on the study of the Hartmann air-jet ultrasonic generator combined with the electrical discharge in the nozzle-resonator gap. Using the schlieren visualization of the air jet and ultrasonic field we investigated the shape and structure of the discharge and we determined relationship among the acoustic field in the nozzle-resonator gap, generator ultrasonic emission and discharge behavior. Apart of the fact that the discharge in the nozzle-resonator gap is stabilized and becomes more uniform the obtained results can be summarized in the following way:

- The discharge increases its volume when the generator works in the regime of ultrasonic generation.
- Fragmentation of the discharge light emission in the regime without the ultrasonic generation is suppressed and the light emission becomes more uniform in the regime of ultrasonic generation.
- Impedance of the discharge is decreased in case when the generator works in the regime of ultrasonic emission.

Acknowledgements

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